

ARIZONA DEPARTMENT OF TRANSPORTATION

REPORT NUMBER: FHWA-AZ92-217

MEASUREMENT OF PAVEMENT SMOOTHNESS FOR CONSTRUCTION QUALITY CONTROL

Final Report

Prepared by:

R.F. Carmichael
L.O. Moser
W.R. Hudson
ARE Inc.
2600 Dellana Lane
Austin, Texas 78746

February 1992

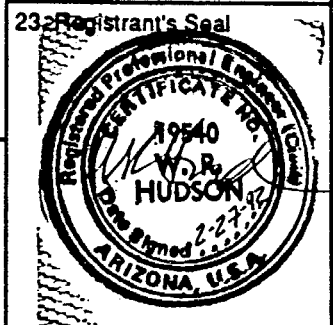
Prepared for:

Arizona Department of Transportation
206 South 17th Avenue
Phoenix, Arizona 85007
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

The contents of the report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Arizona Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. Trade or manufacturers' names which may appear herein are cited only because they are considered essential to the objectives of the report. The U.S. Government and The State of Arizona do not endorse products or manufacturers.

Technical Report Documentation Page

1. Report No. FHWA-AZ92-217	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle MEASUREMENT OF PAVEMENT SMOOTHNESS FOR CONSTRUCTION QUALITY CONTROL		5. Report Date February 1992	
		6. Performing Organization Code	
7. Author(s) R.F. Carmichael, L.O. Moser, and W.R. Hudson		8. Performing Organization Report No.	
9. Performing Organization Name and Address ARE Inc 2600 Dellana Lane Austin, Texas 78746		10. Work Unit No.	
		11. Contact or Grant No. HPR-PL-1-29(217)	
12. Sponsoring Agency Name and Address ARIZONA DEPARTMENT OF TRANSPORTATION 206 S. 17TH AVENUE PHOENIX, ARIZONA 85007		13. Type of Report & Period Covered FINAL/November 1985 - February 1992	
		14. Sponsoring Agency Code	
15. Supplementary Notes Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration			
<p>16. Abstract This research study of pavement smoothness measurement was conducted in order to develop and implement an improved highway smoothness construction specification on asphalt concrete pavements. Achieving a higher level of smoothness on highways during construction results in savings to the taxpayer due to reduced wear and tear on vehicles, and longer highway life. Although the current ADOT specification used for highway smoothness addresses localized smoothness problems, it is difficult to administer due to the measurement system used, and provides little impetus to the contractor to improve his quality of work with respect to overall highway smoothness.</p> <p>This study provided data to assist ADOT in developing a new smoothness specification that would provide incentive to contractors to construct smoother pavements and which is easier for ADOT to administer. In order to provide incentive to contractors, a pavement smoothness construction quality control draft specification and associated measurement procedure was produced.</p> <p>Based upon these criteria, this study has recommended several changes to the ADOT highway smoothness specification for asphalt concrete highways:</p> <ul style="list-style-type: none"> • relative to measurement <ul style="list-style-type: none"> a. new smoothness measurement technique b. different smoothness measuring device used • relative to the specification <ul style="list-style-type: none"> a. accommodation of the new smoothness measurement procedure b. inclusion of an incentive/penalty clause <p>The envisioned consequences of these changes is that the contractors would not only have the incentive to improve highway smoothness quality, but also the means, as provided by ADOT, to assess smoothness quality in a timely manner, improve that quality as needed, and then adjust normal construction procedures in order to construct smoother highways.</p>			
17. Key Words pavement smoothness, pavement roughness, construction quality control of pavements		18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classification (of this report) Unclassified		20. Security Classification (of this page) Unclassified	
21. No. of Pages		22. Price	



ACKNOWLEDGEMENTS

The authors of the report wish to acknowledge the cooperation and work of the Pavement Smoothness Committee for the Arizona DOT. This committee currently includes the following engineers who have participated and worked toward the development of these results: Mr. Larry Scofield, Arizona Transportation Research Center, Mr. George Way, Materials Division, Mr. Jim Delton, Materials Division, Mr. Oscar Mousavi, Materials Division, Mr. Douglas Forstie, Materials Division, and Mr. Tom Warne, Construction Division. The assistance of these engineers and other ADOT personnel is gratefully acknowledged.

In addition, the following personnel at ARE, Inc should be acknowledged for their contributions and hard work to this project. These include: Mr. Eric Moody, Staff Engineer, Mr. Larry Caldwell, Staff Engineer, Mr. Leonard O. Moser, Systems Analyst, Dr. Waheed Uddin, Staff Engineer, and Mr. Gary Elkins, Staff Engineer. Finally, the editing, production, and development of this report would not have been possible without the strong support of the ARE, Inc administrative team including Ms. Verna Pinkerd and Mr. Mike McCullough. The success of the project is due to the fine efforts of these many personnel.

A handwritten signature in black ink, appearing to read "W.R. Hudson", with a long horizontal flourish extending to the right.

Dr. W.R. Hudson, P.E.
Principal Investigator

A handwritten signature in black ink, appearing to read "R. F. Carmichael III", with a stylized flourish at the end.

R. Frank Carmichael III, P.E.
Co-Principal Investigator

TABLE OF CONTENTS

<u>Chapter</u>	<u>Page</u>
1 INTRODUCTION	1-1
GOALS, OBJECTIVES AND SCOPE OF THE STUDY	1-2
DESCRIPTION OF TASKS, PHASES, AND WORK ITEMS	1-3
REPORT FORMAT	1-5
2 SELECTION OF SMOOTHNESS MEASURING EQUIPMENT	2-1
LITERATURE/OFFICE EVALUATION	2-1
RECOMMENDATIONS	2-2
CANDIDATE ROUGHNESS EQUIPMENT SELECTION	2-3
COMPARISON OF CANDIDATE DEVICES	2-6
PRELIMINARY EQUIPMENT TESTING & EVALUATION PLAN	2-10
FIELD TESTING OF CANDIDATE ROUGHNESS EQUIPMENT	2-12
PRIMARY EVALUATION OF CANDIDATE EQUIPMENT	2-29
EQUIPMENT SELECTION FOR CONSTRUCTION SMOOTHNESS ACCEPTANCE TESTING	2-50
CONSEQUENCES OF EVALUATION	2-53
3 SPECIFICATION DEVELOPMENT	3-1
RESULTS	3-1
SPECIFICATION DEVELOPMENT WORK ITEMS	3-1
WRITE THE FIRST DRAFT SPECIFICATION	3-5
PROJECT TESTING AND EVALUATION OF SMOOTHNESS ON NEWLY CONSTRUCTED PAVEMENTS	3-7
JUSTIFICATION OF SPECIFICATION QUANTITIES	3-20

TABLE OF CONTENTS
(continued)

<u>Chapter</u>	<u>Page</u>
4 MAYSMEETER TESTING CAPABILITY	4-1
ACQUIRING A MAYSMEETER CAPABILITY FOR CONSTRUCTION QUALITY CONTROL	4-2
CALIBRATE THE MAYSMEETERS	4-3
IMPLEMENT FIELD TESTING USING THE MAYSMEETER	4-6
5 PROFILOMETER TESTING CAPABILITY	5-1
PROJECT WORK ACCOMPLISHED	5-1
ASSIST IN PERSONNEL RECRUITMENT FOR ADOT	5-3
PURCHASE THE 690D PROFILOMETER	5-3
RECEIPT AND CHECK OUT THE PROFILOMETER	5-4
FULL SCALE FIELD TESTING	5-5
SHAKEDOWN PROBLEMS	5-5
SUMMARY	5-5
6 SUMMARY AND RECOMMENDATIONS	6-1
SUMMARY	6-1
CONCLUSIONS	6-1
FUTURE WORK RECOMMENDATIONS	6-1
REFERENCES	R-1
APPENDIX A - METHOD OF TEST FOR DETERMINING PAVEMENT SMOOTHNESS	A-1
APPENDIX AA - EQUIPMENT OPERATIONAL GUIDELINES	AA-1

TABLE OF CONTENTS
(continued)

<u>Chapter</u>	<u>Page</u>
APPENDIX AB - PROFILOMETER CALIBRATION	AB-1
APPENDIX AC - PROFILE SURVEY OF CALIBRATION SECTIONS	AC-1
APPENDIX AD - MAYSMETER CALIBRATION	AD-1
APPENDIX AE - MAYSMETER CALIBRATION CONTROL	AE-1
APPENDIX B - MAYSMETER ROUGHNESS DIFFERENTIAL DUE VEHICLE SPEED ANALYSIS	B-1
APPENDIX C - MAYSMETER ROUGHNESS DIFFERENTIAL DUE CHANGING CLIMATIC ZONE ANALYSIS	C-1
APPENDIX D - TWO PARTIAL FACTORIAL ANALYSES OF MAYSMETER ROUGHNESS	D-1
APPENDIX E - FOUR CELL MAYSMETER DATA ANALYSIS	E-1

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1-1 Report Chapter/Project Task Relationship	1-7
2-1 Comparisons of Pavement Roughness Devices	2-8
Comparisons of Pavement Roughness Devices (cont'd)	2-9
2-2 Average Roughness Estimates for Selected Austin, Texas Test Sections	2-13
2-3 A Comparison of Various Parameters Associated With the Roughness Field Tests	2-20
2-4 List of Test Sections Used for Profilograph Tests	2-27
2-5 Summary of Roughness Data	2-30
2-6 Summary Statistics of Model 8300 RS Reliability Test Data	2-31
2-7 A Summary of Evaluation and Ranking of the Candidate Roughness Devices	2-33
2-8 Overall Ranking of the Candidate Devices	2-34
2-9 Life-cycle Cost Analysis of Pavement Smoothness Measurements	2-41
Life-cycle Cost Analysis of Pavement Smoothness Measurements (cont'd)	2-42
2-10 Alternative Life-cycle Cost Analysis of Pavement Smoothness Measurement Equipment	2-43
2-11 Summary of Maysmeter Evaluation Telephone Survey	2-46
3-1 Original Factorial Design and Sections Found	3-9
3-2 Database of Arizona DOT Maysmeter Roughness Measurements	3-13
Database of Arizona DOT Maysmeter Roughness Measurements (cont'd)	3-14
3-3 Preliminary Maysmeter Value Results of ADOT Maysmeter Field Test Plan	3-17

LIST OF TABLES
(continued)

<u>Table</u>	<u>Page</u>
3-4 Statistically Derived Results of Maysmeter Target Smoothness Data Analysis	3-19
3-5 Comparison of Maysmeter Target Smoothness Alternative Categorizations Using ADOT Smoothness Data (in/mi)	3-23
3-6 Target Smoothness Results Using ADOT Maysmeter Data (in/mi) and Georgia DOT Smoothness Categories	3-24
3-7 Recommended Maysmeter Target Smoothness Values (in/mi)	3-25
3-8 Penalty Due to a 2-Year Pavement Life Loss (as a % of construction cost)	3-31
AD-1 Input Data Format for AZCALIB Program	AD-5

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
2-1 A Sample Data Collection Form Used During Roughness Measurements	2-19
2-2 A Sample of Partial Output of the 690D Profilometer Data	2-22
2-3 A Sample Output of Model 8300 RS Data	2-24
2-4 Example of a Strip Chart Record of the California Profilograph	2-28
2-5 Illustration of the Extent of Variability in the Roughness Data Measured by the California Profilograph and Maysmeter	2-52
AA-1 Schematic of Maysmeter Transmitter Showing Position of Lamp for Replacement	AA-4
AE-1 Maysmeter Control Form for 5 Monitoring Runs	AE-4
AE-2 Maysmeter Control Form for 10 Monitoring Runs	AE-6
AE-3 Maysmeter Control Form for 15 Monitoring Runs	AE-8
AE-4 Worksheet for Calculation of \bar{X} and S	AE-9

LIST OF DOCUMENTS AND FORMS

<u>Document No.</u>		<u>Page</u>
1	PAVEMENT SMOOTHNESS SPECIFICATION FOR AC	3-2
	PAVEMENT SMOOTHNESS SPECIFICATION FOR AC (cont'd)	3-3
2	ARIZONA TEST METHOD 829	3-4

<u>Form No.</u>		
1	CALIBRATION SECTION HRI	AC-5